RESEARCH ARTICLE | JUNE 07 2024

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AIP Conf. Proc. 2991, 020035 (2024)
https://doi.org/10.1063/5.0198572

Carbon Footprint Reduction Potential for Diesel-Fuelled Generators Through Periodic Maintenance Using EXORIN Treatment

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Abstract. Climate change and greenhouse gas emissions are among the most pressing global issues, with reduction of carbon footprint has been identified as one of the main indicators in this battle. In the effort to reduce carbon footprint generation, a local power utility company, located in East Malaysia that operates diesel-fuelled generators had conducted a periodic maintenance program using EXORIN treatment. EXORIN treatment program focused on improving the fuelling capability of the diesel-fuelled generators. Using comparative tests from untreated and treated operations, the carbon footprint emission levels were determined by comparing data obtained from gaseous emission sampling method, dark smoke observation and data of stationary source from the utility powerplant. From analysed data, CO and CO_2 emissions were successfully reduced by around 7%. The combustion and energy efficiencies had also improved within the range of 9% to 21%. Fuel economy, which is dependent on the consumers electricity demands, also showed significant trend. These results outlined the potential of reducing carbon footprint using the dedicated EXORIN treatment program.

INTRODUCTION

A diesel-fuelled generator is primarily composed of a compression ignition (C.I.) engine, an asynchronous electric generator, and related mechanical-electrical system. This type of powerplant is known for its durability and ability to consume fuels that contain similar cetane index as the conventional fossil-based diesel fuel [1]. Heavy-duty C.I. engines can also give years of reliable services, provided they are given good maintenance program as this will ensure continuous delivery of engines' peak performance and affordable operating costs. Nevertheless, the greenhouse gases (GHG) and particulate matters (PM) emissions from C.I. engines have caused a major concern to the industrial users, especially in the context of abiding with the ever-stricter emissions regulations [2, 3]. Awareness on green investment and the need to combat climate change have also encouraged investors to refer to carbon footprint data and rate of adoption of low-carbon technology as their decision-making factors, before committing to new investments [4, 5].

Diesel-fuelled generators have been the choice by Sabah Electricity Sdn. Bhd. (SESB), a power utility company that is responsible for providing electricity to the Sabah state. Most of SESB power plants are already operating under very long hours and drastic maintenance intervention is needed to ensure these diesel-fuelled generators are still capable to generate electricity matching the demands from the users. If these generators are forced to operate using poor quality fuels, the power utility will generate lower electricity and releasing more hazardous emissions to the environment. Apart from the influences from the geometries of the C.I. engines [6, 7], their operating efficiency can be improved by enhancing the fuelling system operating performance.

Diesel-fuelled generator also uses very high compression ratio for combusting the diesel fuel and continuous operation will encourage the formation of carbon deposit inside the combustion chamber with higher release of

Proceedings of the International Conference on Green Engineering & Technology 2022 (IConGETech 2022)
AIP Conf. Proc. 2991, 020035-1–020035-6; https://doi.org/10.1063/5.0198572
Published under an exclusive license by AIP Publishing. 978-0-7354-4967-1/$30.00

hazardous emissions. Consequently, long hours operation will reduce the fuel injection efficiency of the C.I. engine. Operational record shows that the diesel-fuelled generator under investigation was not able to maintain optimum performance as it did not undergo any fuelling and engine treatment process. Hence, it was proposed that SESB to undertake a C.I. engine treatment study using solutions produced by EXORIN - a local company specialising in producing treatment solutions, which focus on cleansing the fuelling system, resulting to an enhanced combustion efficiency [8]. In this present study, the outcomes from conducting maintenance program on the SESB diesel-fuelled generators using EXORIN solutions are presented.

METHODOLOGY

For this study, the selected diesel-fuelled generator for the study used a C.I. engine with the specifications as detailed out in Table 1.

TABLE 1. Specification of the generator's C.I. engine treated using the EXORIN solution

No.	Item	Description
1	Type of installation	Generator set on-site
2	Generator engine model	Caterpillar 3512TA (Turbocharged-aftercooled, V12, 4-stroke Water-cooled C.I. engine)
3	Bore x Stroke	6.69 in x 7.48 in / 169.93 mm x 190.00 mm
4	Engine capacity	3,161.03 in^3 / 51.80 L
5	Compression ratio	13.5:1
6	Fuel system	Direct unit injection
7	Operating speed	1,500 rpm

Measurements of main emissions that related to carbon footprint assessment were completed using TESTO 350M/XL gas analyser, consistent with the methods described in USEPA Method 3A [9]. The dark smoke observation used to determine if smoke emissions from the stacks were within the permissible limits, were defined and expressed using the Ringelmann Smoke Charts, as stated by Malaysia Department of Environment (DoE) requirements [10]. Fuel consumption data were obtained from the diesel-fuelled generator operating outputs. The exhaust emissions data were collected before and after the treatment using EXORIN solutions. Based on the available emission data, carbon footprint analysis was calculated using carbon monoxide (CO) and carbon dioxide (CO_2) readings.

From start to finish of the treatment, a few parameters have been identified as indicators for assessing the performance of the SESB diesel-fuelled generator: rate of fuel consumption, amount of energy generated, operating speed, and emissions data; all were taken before and after the treatment. Data was collected every month during the 10-month long testing duration: from May 2015 (Month 1) until February 2016 (Month 10), and the treatment process was carried out in August 2015 (Month 4). From March until May 2015, were the observation months before undergoing treatment (BEFORE TREATMENT data); and data from September 2015 (Month 5) until February 2016 were categorised as data after undergoing treatment (AFTER TREATMENT data).

RESULTS AND DISCUSSION

The collected measurements for the diesel-fuelled generators are displayed in Table 2, and the calculated improvements are summarised in Table 3. Emissions data are as outlined in Table 4.

From the tabulated data in Table 2, the average energy generation efficiency (calculated based on the amount of fuel consumed) before the treatment was around 33.05% and this average efficiency was increased slightly to 33.83% after completed the EXORIN treatment. This treatment also improved the generator's energy efficiency by almost 9.8%, as detailed in Table 3. The minimum improvement recorded was almost 16% and the maximum improvement was around 21%. Better fuel consumption rates were observed after the treatment, averaging to around 151 litre/hour, an increase of almost 10 litre/hour, which had enabled the generator to produce higher amount of energy for every litre of fuel that it consumed.

Fuel consumption rate was improved on average by 7.30%, with an improvement by 2.36% for the electricity generation per litre of fuel. Table 4 the emissions characteristics of the treated generator, all major emissions had shown distinct reductions. The very significant improvement in reduction was observed for the HC emission (almost

96% reduction), followed by reduction in NO_X, CO, smoke and CO_2 emissions. These emissions values supported the performance improvement trends exhibited by the generator as outlined in Table 2 and Table 3.

TABLE 2. Selected operating parameters from the diesel-fuelled generator set, treated using the EXORIN solution.

Month	Generator running duration [hour]	Amount of fuel used [litre]	Total energy generated [kWh]	Electricity generated per consumed fuel [kWh/litre]	Efficiency of energy generation	Category of data
M01	343	45,084	157,760	3.499	32.92%	BEFORE
M02	304	42,755	150,100	3.511	33.03%	
M03	352	52,995	187,060	3.530	33.20%	
M04T	285	41,082	147,190	3.583	33.70%	TREATMENT
M05	390	60,404	217,440	3.600	33.86%	AFTER
M06	360	53,743	193,800	3.606	33.92%	
M07	330	48,573	177,310	3.650	34.34%	
M08	356	53,011	189,760	3.580	33.67%	
M09	480	73,626	263,810	3.583	33.71%	
M10	428	65,609	233,370	3.557	33.46%	
M01	343	45,084	157,760	3.499	32.92%	

TABLE 3. Comparison of data before and after the treatment using EXORIN solutions

	Electricity generated per consumed fuel [kWh/litre]	Energy efficiency [kWh/hour]	Fuel consumption rate [litre/hour]
Average before treatment	3.51	495.04	140.88
Average after treatment	3.60	543.51	151.16
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Average improvement	2.36%	9.79%	7.30%
Minimum improvement	1.65%	15.89%	11.98%
Maximum improvement	4.32%	21.22%	17.83%

TABLE 4. Emissions data before and after the treatment using the EXORIN solutions

	Average emissions	
Emission	**Before treatment**	**After treatment**
CO [ppm]	294.67	284.33
CO_2 [%]	8.14	8.09
HC [ppm]	1,433.30	60.00
NO_X [ppm]	1,673.33	1,365.70
Smoke density [%]	18.92	17.42

The plots for the fuel consumption rates and the amount of electricity generated for every litre of fuel consumed are shown in Fig. 1 and Fig. 2, respectively. From these plots, the improvement made by the EXORIN treatment are clearly visible.

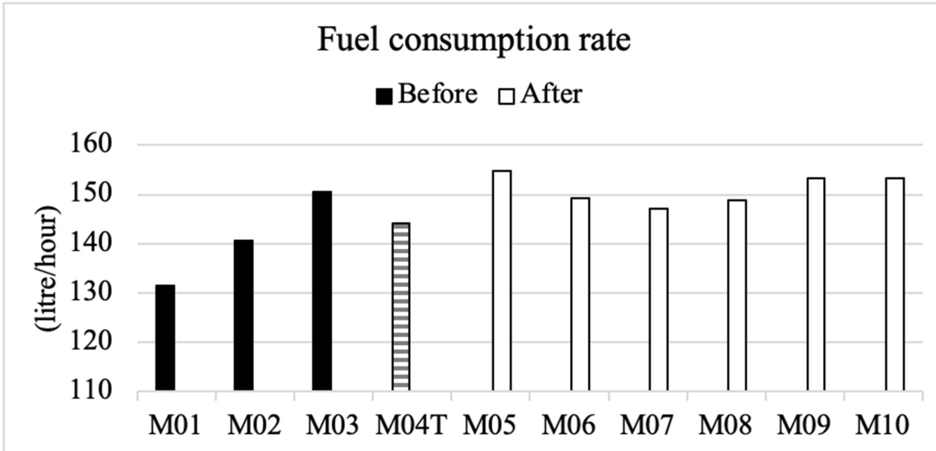


FIGURE 1. Comparison of fuel consumption rate before and after the EXORIN treatment.

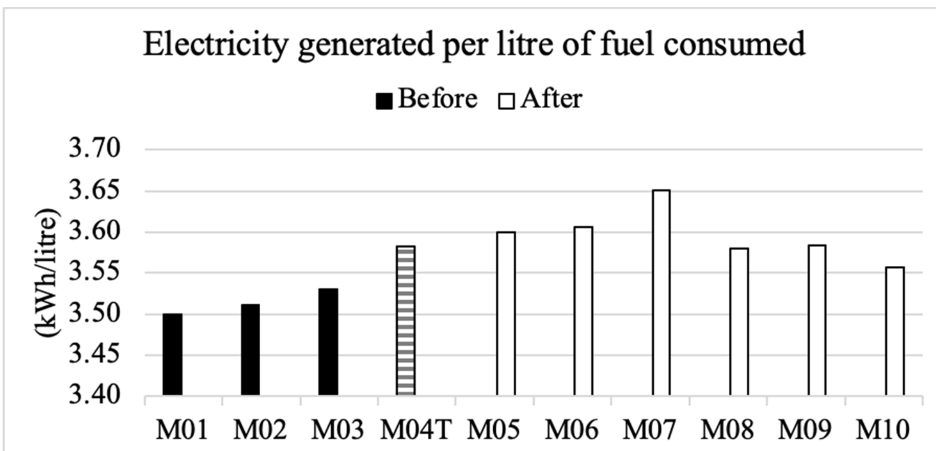


FIGURE 2. Comparison of electricity generated before and after the EXORIN treatment

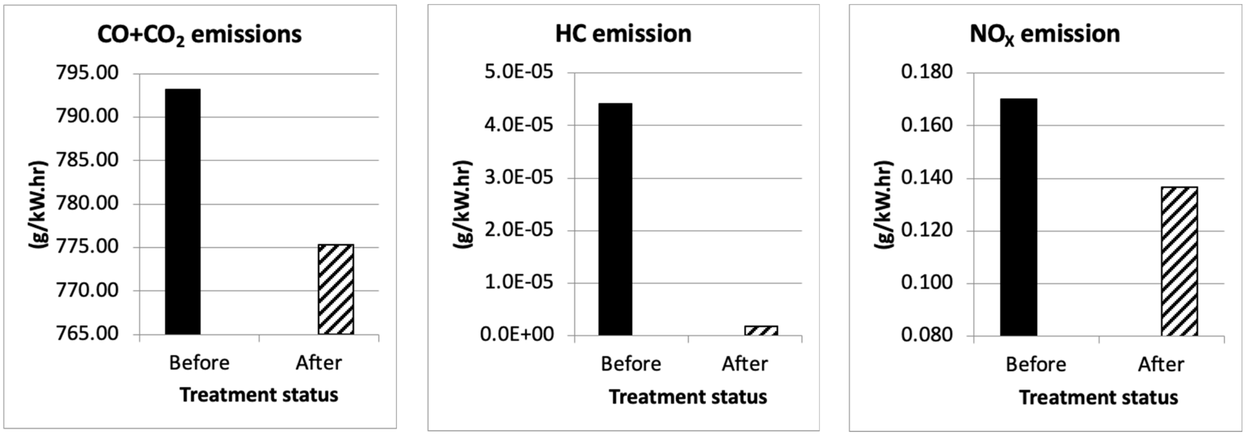
From Fig. 1 and Fig. 2, both parameters show improvement after the EXORIN treatment had been conducted. Fig. 1 shows the average fuel consumption rates from the M05 onwards were much higher than the rates before the treatment was carried out. Moreover, from Fig. 2, the amount of electricity generated was started to drop beginning from M08, which was after four months from the treatment stage. This shows the need for conducting a periodic treatment program, for every six months, to maintain the performance of the generator set. The analysed data also suggests that the generator will be able to maintain its performance further, upon consecutive treatment after six months from the first completed treatment stage.

By improving the fuel delivery and combustion efficiency of the generator's engine, a much higher energy output was able to be produced, for every litre of fuel consumed. Nevertheless, it is also imperative to ascertain that higher energy output would not increase unnecessarily the carbon footprint of the operating generator. Quality of combustion can also be characterised by assessing the emissions generated during the operation [11]. Using the measured emissions and generated energy, from Table 3 and 4, the brake specific emissions for the generator's engine were calculated and tabulated as the following Table 5.

TABLE 5. Brake specific emissions of the generator's engine before and after the treatment using EXORIN solutions

	CO [g/kWh.hr]	**CO_2 [g/kWh.hr]**	**HC [g/kWh.hr]**	**NO_X [g/kWh.hr]**
Before treatment	1.823	791.384	4.415×10^{-05}	0.170
After treatment	1.731	773.607	1.818×10^{-06}	0.137

The comparative plots for the emissions, before and after the treatment are shown in Figure 3: (a) combined CO and CO_2 emissions; (b) for HC emission, and (c) for NO_X emission.



(a) (b) (c)

FIGURE 3. Brake specific emissions values comparison before and after the EXORIN treatment: (a) Combined $CO+CO_2$ emission; (b) HC emission; (c) NO_X emission

From Table 5 and Fig. 3, HC emission showed the highest emission reduction (almost 96% reduction), followed by NO_X emission (almost 20% reduction) and combined $CO+CO_2$ emissions (around 7% reduction). Smoke density was measured to reduce by 7.9%. Enhanced fuelling for the engine promoted better consumption of fuel and resulted to much lower HC emission. This improved combustion operation was translated to more energy being produced by the generator. Reduction for combined CO and CO_2 emissions clearly showed the capability of the EXORIN dedicated solutions to reduce carbon footprint generation, while maintaining operation capability at its optimum level. The treatment process also produced almost comparable outcomes when compared to generators that were using non-conventional fuels, such as the biomass syngas [12]. Similarly, for generators using pyrolysis fuel [13], the performance could also be improved by applying the EXORIN treatment process. Where the choice of fuel is limited, operator of such generators could utilise the EXORIN treatment process to optimise the output from their generators.

CONCLUSION

EXORIN treatment, which focused on cleaning the fuelling and combustion systems, had successfully improved the generator's operating outputs and significantly reduce the release of hazardous emissions to the environment. Generator efficiency was improved within the range of 9% to 21%, with carbon footprint reduction of around 7% and a very high reduction on the HC emission (almost 96%). These quantitative findings fulfilled the objectives that was set for this study. The analysed results also indicated the capability of the EXORIN solutions to assist industrial players to achieve their annual carbon footprint reduction targets. Adoption of periodic maintenance for the diesel-fuelled generator will enable it to produce optimum energy output while suppressing the generation of unwanted carbon footprint. Consequently, the EXORIN product could accelerate the country's interest to move towards low carbon economy.

ACKNOWLEDGMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Geran Sepadan RE-SIP M061 in collaboration with EXORIN Technologies Sdn. Bhd. The cooperation and support given by Sabah Energy Sdn. Bhd. (SESB) throughout this study is also kindly acknowledged.

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